An Automated Approach and Virtual Environment for Generating Maintenance Instructions

Russell S. Blue[1], Jeff Wampler[2], G. Bowden Wise[1], Louis J. Hoebel[1], Boris Yamrom[3], Christopher R. Volpe[1], Bruce Wilde[4], Pascale Rondot[1], Ann E. Kelly[1], Anne Gilman[1], Wesley Turner[1], Steve Linthicum[1], George Ryon[1]

[1]General Electric Corporate R&D Center
One Research Circle
Niskayuna, NY 12309 USA
+1 518 387 5560, blue@crd.ge.com

[2]Air Force Research Laboratory (AFRL/HESS)
[3]The City University of New York (Lehman College)
[4]Lockheed Martin Systems Integration (Owego)

ABSTRACT
Maintenance of complex machinery such as aircraft engines requires reliable and accurate documentation, including illustrated parts catalogs (IPCs), exploded views, and technical manuals describing how to remove, inspect, repair and install parts. For new designs, there are often time constraints for getting a new engine to the field, and the available documentation must go with it. Authoring technical manuals is a complex process involving technical writers, engineers, as well as domain experts (mechanics and designers). Often, several revisions are required before a manual has correct IPC figures and maintenance instructions. Compounding this problem is that technical writers often perform tasks better suited for computers, leading to increased costs and errors.

In this demonstration, we describe a new framework to generate maintenance instructions from solid models (Computer Aided Design/CAD data) and then validate these instructions in a haptics-enabled virtual environment. Our approach utilizes natural language processing techniques to generate a presentation-independent logical form, which can be transformed for display within the virtual environment. During the development of the system, task analyses, human models, usability studies, and domain experts were used to gain insights. The end result is a more integrated and human-centered process for developing technical manuals, providing higher quality documents with less cost.

Keywords
Maintainability Analysis, Maintenance Manual Development, Natural Language, Text Generation, Virtual Environments, Haptics, Human-Centered Design, XML

INTRODUCTION
One of the stumbling blocks of maintainability analysis is the difficulty of not being able to rehearse maintenance on the design before it is finished. Once a design is complete, it is often too late (and expensive) to make significant changes for the sole purpose of maintainability. Of course, the cost of not making these changes haunts the technicians for the life of the system.

Technical writers must obtain data from numerous sources to assemble maintenance manuals. This labor-intensive task adds excessive cost to the development of complex systems such as aircraft [1]. Not only are the manuals expensive, they are often developed under extreme time constraints in a process that is not well integrated with the design, resulting in inaccurate, outdated, and incomplete maintenance documentation. These shortfalls result in more maintenance downtime, more lifecycle costs and may have been a contributing factor in accidents [2]. Many reasons can be cited for these shortfalls, but a major contributor is the lack of an integrated, human centered design approach for maintenance manual development.

Here, we describe a new framework and architecture for maintenance manual development, called Service Manual Generation (SMG). This demonstration highlights developments and extensions of three SMG enabling technologies: 1) modeling, simulation, and analysis of design geometry for maintenance; 2) natural language generation of a maintenance logical form from design data and 3) user interaction advances in a haptics-enabled virtual environment for maintainability analysis.

SERVICE MANUAL GENERATION
SMG will change the maintenance manual process to afford the maintainability engineer an early and more immersed view of the maintenance procedures for analysis (access, position, tool use, forces required, etc.)[3][4]. This change will allow a more concurrent input from a maintainability perspective, paving the way for the critical design flaws to be corrected in a timely and cost effective manner. SMG is based on three integrated modules: 1) Service Sequence (SS), 2) Task Generation (TG) and 3) Virtual Validation (VV). The SS module provides an instant disassembly sequence to be viewed by the analyst, the TG module composes a draft technical manual based on the disassembly sequence, and the VV module provides the immersion for realistic and meaningful validation.

CHI 2002, April 20-25, 2002, Minneapolis, Minnesota, USA.
ACM 1-58113-454-1/02/0004.

SERVICE SEQUENCE

The SMG system starts with the Service Sequence module, leveraging a three-dimensional representation of the geometry to automate the generation of a sequence of actions suitable for performing a particular maintenance task. To determine a disassembly sequence, our approach uses a visualization package (such as GE's Galileo), user input, various heuristics, and a non-directional blocking graph [5]. The output of the SS module is an XML disassembly sequence describing the order and direction of part removal (including images and animations). Optionally, for Remove and Replace (R&R) procedures, the XML sequence would contain reassembly information. The system is also adapted for the generation of exploded views for use within IPCs and other technical documentation.

TASK GENERATION

Generating instructions that a technician can use in the field requires information beyond the geometrical model of the equipment, such as safety warnings, notes on materials, and text directions. The TG module takes the service sequences and related images as input and produces a language- and presentation-independent logical form in XML format. For each step in the sequence, appropriate domain information is incorporated into the logical form. In addition, the structure of repair and installation tasks is used to organize this information comprehensibly for the technician [6]. Our lexicon allows retrieval of the appropriate action verb in different styles or languages. The logical form's modular design can function in different product lines (e.g., fighter aircraft vs. commercial jet engines) and domains (e.g. aircraft engines vs. power turbines).

VIRTUAL VALIDATION

The coupling of manuals and design in SMG provides an innovative approach to procedure validation. The design information from the CAD environment is used within a haptically-enabled virtual environment, which integrates various virtual reality technologies (e.g. data glove, trackers, stereo Helmet Mounted Display) and a haptic device (to supply force feedback to the user). This environment is used for two separate validations: one of the computed service sequence itself to ensure that the sequence is correct, and another of the Task Generation output, to ensure that the collection of text and images is unambiguous and leads the analyst to carry out the task in the manner specified by the service sequence.

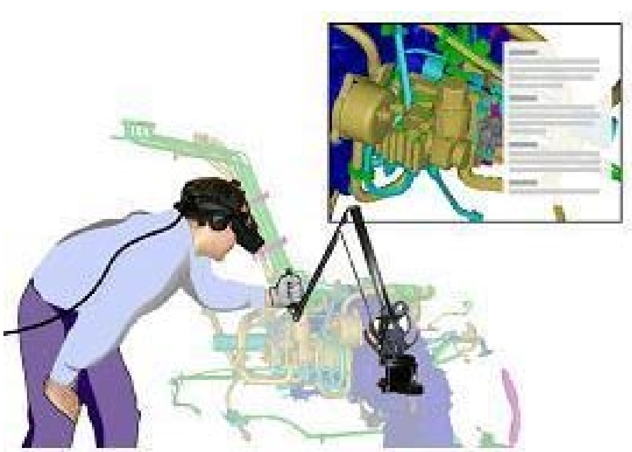

Figure 1: Validating maintenance instructions in a haptics-enabled virtual environment using the Phantom [7].

TAILORED INFORMATION DELIVERY

The logical form represents all of the potential interactions independent of the data requirements for a particular application and is thus flexible enough for multiple end-user applications. By defining the logical form in XML, different stylesheets may be used to transform the logical form to the desired presentation format. This enables the same logical form to be used to deliver the generated instructions to a virtual environment, traditional web pages in HTML, or to be used as input to another system, such as an authoring environment for interactive electronic technical manuals (IETMs).

ACKNOWLEDGMENTS

We would like to thank Ed Boyle and John Ianni for initiating the research solicitation for the SMG program.

REFERENCES

1. Sanchez, E., Winning, S., Boyle, E.S. *Automated Support for Maintenance Technical Manuals*. Air Force Armstrong Laboratory Technical Paper (AL/HR-TP-1997-0051).
2. Chaparro, A. and Groff L. S., Human Factors Survey of Aviation Technical Manuals, Phase 1 Report: Manual Development Procedures DOT/FAA/AR-xx/xx, 2001.
3. Kroll, E., Beardsley, B., Parulian, A. A Methodology to Evaluate Ease of Disassembly for Product *Recycling, IIE Transactions, 28*, 837-845, 1996.
4. Badler, N., Erignac, C., Vincent, P., Sanchez, E., Boyle, E.S., Wampler, J.L., Ianni, J.I. *Design Concepts for Automating Maintenance Instructions*. Air Force Research Laboratory Technical Report (AFRL-HE-WP-TR-2000-0088).
5. Wilson, Randall H. On Geometric Assembly Planning. PhD Thesis, Stanford University, March 1992.
6. Shank, R. Scripts, Plans, Goals and Understanding: An Inquiry into Human Knowledge Structure. Lawrence Erlbaum Associates, Hillside, NJ, 1977.
7. Massie, T.M., Salisbury, J.K. The PHANToM Haptic Interface: A Device for Probing Virtual Objects. ASME Haptic Interfaces for Virtual Environment and Teleoperator Systems 1994, In *Dynamic Systems and Control*, vol. 1 (Nov. 6-11, 1994), pp.295-301.